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Contribution of wind power and CHP to exports from Western Denmark during 2000 to 2004

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ABSTRACT

The experience of Denmark is used by the United Kingdom's anti-wind lobby to demonstrate that intermittency and inaccuracies in wind forecasting make wind power ineffective and expensive. A further assertion is that most of the power is 'unwanted' since up to 80% of it is exported. Here, available data for Danish energy production for 2000 to 2004 is used to assess the link between wind generation and exports and test the validity of these claims.

Net exports in Western Denmark showed good correlation with wind production. However, they were more significantly correlated with the production from local combined heat and power (CHP) plants. In order to test the 80% export claim, a simple technique was devised to correlate and rank hourly net exports and generation from wind and local CHP. In the case where net exports were primarily attributed to (or blamed on) wind, 44 to 84% of annual wind production was deemed to be exported, with wind 'causing' 57 to 79% of net annual exports. For this extreme scenario the percentage values are in line with those of critics. However, under the opposite extreme scenario in which exports are attributed to local CHP, 77 to 94% of exports were caused by CHP and only 4 to 32% of wind production was exported.

Overall, this study shows that there is some degree of correlation between net exports and wind power, but that the claim that 80% is exported is unwarranted since it ignores the demonstrably stronger influence of local CHP.

Keywords: exports, combined heat and power, Denmark, wind power

Word count: 3,700 words

1 Introduction

In the United Kingdom (UK), the Government has proposed an aspirational target of 20% electricity supply from renewables by 2020, with the largest contribution expected from wind power. While independently-conducted polls suggest a significant level of support for wind power among the general public [1], the debate is often dominated by active and vocal critics. While the prime arguments of the anti-wind lobby relate to visual intrusion, other aspects relate to the ‘efficiency’ of wind turbines [2], often mistakenly using the low capacity factors as evidence of their negligible impact on energy production and carbon reduction. A further argument revolves around the ability of the electrical network to absorb ‘intermittent’ wind, although the UK Energy Research Centre’s persuasive report [3] concludes that it is not a serious difficulty. It has been common for the anti-wind lobby to quote Danish experience with wind as indicating why the UK should not expand its wind capacity. In particular, Danish experience is deemed to indicate that the variable nature of the wind, together with inaccuracies with wind forecasting, make wind power ineffective for assuring reliable power supplies [2]. Additionally, there are claims that wind power is effectively ‘unwanted’ since 80% of the wind energy produced in Denmark is exported [4], [5]. In this paper, a close examination is made as to whether such claims about export levels can be substantiated from publicly available Danish electricity statistics.

This paper starts with a description of the main features of the Danish electricity system (Section 2). Section 3 examines available statistics for Denmark, and Western Denmark in particular, to assess whether wind power may indeed be linked to periods of ‘excess’ production. Section 4 introduces a simple technique to evaluate how net exports can be attributed to (or blamed on) wind power and/or to CHP, before the findings are discussed.

2 The Danish Electricity System

2.1 A unique situation

Denmark is unique in the extent of wind power utilisation on its power network. The country met 14% of its 33 TWh/yr electricity demand from wind in 2002. It is also endowed with a very high level of integration with neighbouring countries: in 2002, it was able to import almost 9 TWh, and export 11 TWh [6], representing 27% and 33% of domestic demand respectively.

2.2 The Danish Networks

The transmission network has historically been administered by two independent Transmission System Operators (TSOs): Eltra in the West, and Elkraft in the East (on Zeeland and neighbouring islands). In 2005, these merged to form the new state-owned operator, Energinet Danmark which also oversees operation of the gas network. The two separate TSOs arose because their respective networks were geographically and electrically separate from each other as Figure 1 shows. While not directly connected, both are interconnected to neighbouring countries. Western Denmark is synchronised with Germany (and the UTCE system) and has 1670 MW of DC links with Norway and

Sweden [7]. Eastern Denmark is part of the NordPool market and is connected synchronously to Sweden and asynchronously to Germany. While the physical transfer capability is significant, there are operational limits of 800 MW to the North and 1300 MW to the South because of congestion on their neighbours' grids.

The TSO is responsible for ensuring the physical stability of the systems by maintaining frequency through continuous supply and demand matching. It also handles 'prioritised production': must-take production that receives a minimum, legally guaranteed price and includes wind power and some CHP, as well as facilitating power transfers between the NordPool and German systems.

2.3 Electricity production in Denmark

Danish Energy Authority (DEA) data [9] shows that the *gross* electricity production in 2002 was 39.3 TWh, with the breakdown as presented in Figure 2. Combined Heat and Power (CHP) powered by fossil fuels are the dominant form of generation: 84% of the 2002 production came from CHP, although only 48% was actually produced in combination with heat, the remainder being from separate electricity production alone [9]. The use of CHP for district heating is commonplace. Through taxation and subsidies, CHP plants have financial incentives to run at times when electricity is most needed. In winter, many CHP plants produce electricity during the day when the load is high, and store heat for distribution. However, their electricity output is influenced principally by the requirements for heat rather than by demand for electricity. Monthly wind production data from the DEA [6] indicates that Danish wind capacity factors are around 20%, which is low compared to 27.4% reported for the UK in 2005 [10] and very low relative to the record 57.9% for the Burradale farm in Shetland in 2005 [11].

2.4 TSO Management of wind power and CHP

Under Danish law, the power from small-scale CHP and wind must always be accommodated on the networks, and is 'prioritised'. These energy sources are also major contributors, with 50% of the energy production in the Eltra area classed as prioritised in 2001 [12]. Since electricity from prioritised wind and CHP is 'must-take', the TSO must predict the load and the production as accurately as possible, between 36 and 12 hours ahead of time. For CHP, this is partly done on the basis of temperature forecasts, since these strongly dictate heat production in winter. Wind is more difficult to predict accurately, and there have been days when the system stability has been at risk in Western Denmark, although this is largely due to the 12 hour scheduling lead-time employed in the Danish system.

3 Analysis of Danish electricity statistics

3.1 Monthly data for Denmark

Monthly average production, imports, exports and supply for the years 2000 to 2004 were obtained from the Danish Energy Authority [6]. Figure 3 shows that Denmark as a whole is usually a net exporter in winter months and a net importer in summer months.

Figure 3 also shows that wind power production represents a minor, though noticeable, share of the total mix. It is evident that there are seasonal patterns in the data and this section takes a closer look at these, as well as exploring the relationships between them.

3.1.1 The influence of demand on imports

Monthly imports were regressed against demand which, as Figure 4 implies, appears to be inversely correlated with imports. While this may appear counter-intuitive, the reason is apparent once seasonal effects are considered by separating winter months (defined here as October to March) from summer months (April to September). In summer, monthly demand is always below 2900 GWh and imports are nearly always above 650 GWh. By contrast, winter demand is always greater than 2900 GWh, and imports are nearly always between 350 and 650 GWh. To a large extent this seasonal pattern can be attributed to the increased winter usage of district heating, where significant electrical co-production makes imports less necessary, despite the higher overall electrical demand. As evidenced by the very low regression coefficients, it appears that (at the monthly aggregate level at least), domestic demand has limited influence on imports in winter.

3.1.2 Net exports and wind power production

For Western Denmark alone, monthly net exports showed some degree of correlation (R^2 = 0.4) with monthly wind power production (Figure 5). The vast majority of summer months yielded a wind power production below 400 GWh and they included 16 out of 17 of the months during which there were net imports. A similar result was obtained for the whole of Denmark, although the distinction between seasons was less marked. In both cases, there was a trend to higher net imports and low wind power production during summer months.

3.1.3 Net exports and local CHP production

The seasonal impact of local CHP can be clearly in Figure 6, which shows monthly local CHP production against net exports in Western Denmark. It appears that low local CHP power production corresponds to low net exports. The degree of correlation (R^2 = 0.70) indicates that, in determining net exports, local CHP activity may be more relevant than wind power production.

3.1.4 Local CHP and wind power: coincident production

Although wind power production is not as strongly correlated to the level of net monthly exports as local CHP output, higher winter wind speeds could have a compounding effect on the need for exports. Figure 7 plots monthly production from local CHP against monthly wind power production for Western Denmark. It is clear that wind production reaches its highest level in winter, coincident with higher production from CHP plants. Although not shown in Figure 7, when there is no distinction made between seasons there is a mild correlation between monthly local CHP and wind production (R^2 = 0.29). However, where seasonal factors are included it is apparent that these power sources are virtually independent, as evidenced by the very low correlation factors.

3.2 Hourly data for Western Denmark

While the monthly statistics from the DEA are convenient for appraising the obvious relationships over several years, it is not possible to answer more specific questions regarding the relationships between wind power output and export levels. Hourly production, demand and inter-connector loadings were available online for the Western Danish system [8], allowing more detailed inspection.

Figure 8 shows hourly net exports plotted against the percentage of demand met by wind in each hour during the year 2000. The data for January to March is neatly separated from that for July to Sept, and both show a reasonable correlation ($R^2 = 0.5$). Both sets of data are distributed along broadly parallel lines, indicating an average of around 17.5 MW of export per percentage point of demand met by wind. The separation of the two lines is around 748 MW, which would be in line with the additional output of CHP in winter months.

A similar plot for local CHP production is given in Figure 9. Consistent with what was found in the previous section, most of the data for January to March is located in a region in which CHP production meets more than a third of the demand, and where net exports occur. In contrast, July to September sees local CHP producing between a tenth and a third of hourly demand, which tend to correspond to hours of net import. It is interesting to note that the correlation for the whole year was nearly as good as for the wind data in the two subsets ($R^2 = 0.47$). This reflects the fact that CHP production varies over the full range of its values according to seasonal influences rather than on a daily basis, which contrasts with the greater day-to-day variability of wind. Importantly, there is a much larger change in export per percent change in demand (29 MW/%), indicating that in 2000 the influence of local CHP on net exports was more significant than that of wind.

Finally, the combined influence of wind and local CHP is shown in Figure 10. The major difference from Figures 8 and 9 is the extent of demand met by these sources. With local CHP and wind together, production exceeds demand for a significant number of hours, leading to significant net export. These instances of network overload were highlighted by Søbrinck [13].

4 Evaluating wind and local CHP contribution to net exports

The earlier sections demonstrate that it is the combined influence from wind and local CHP that defines the export. In order to move beyond issues of correlation to consideration of causality, it is necessary to explore their respective contributions. Figures 8 to 10 suggest a very different influence in time, with local CHP contributing a seasonal ‘baseload’ to net exports and wind being additional to this. The existence of correlations between exports and power produced from wind or local CHP could induce us to exploit the linear fit formulae to estimate the respective contributions of wind and local CHP to net exports. However, given the spread of the data this would be at best a crude estimate. For example, Figures 8 and 9 show that, on the basis of the gradients of the trendlines, CHP had an influence nearly twice as strong as wind power. Nevertheless, there may be clear instances when the combination of high wind and low

CHP production would mean that most exports are contributed by wind, and vice versa. Therefore, it was decided to use a procedure that exploits the hourly data in a more thorough manner.

We distinguish two extreme scenarios depending on which of the two production sources the export is attributed, (or in other words, which is deemed to have 'caused' the export).

1. Scenario 1 attributes recorded net exports to wind up to the maximum production available. Any export in excess of wind production is attributed to local CHP.

2. Scenario 2 attributes net exports first to local CHP production, and any residual exports to wind.

By processing the hourly data according to these two scenarios, upper and lower bounds can be placed on the respective contributions to net exports from each power source. Positive net imports were ignored, since it would be difficult to apportion shortfalls between wind and local CHP production. The following procedure was devised:

1. Hourly net export, wind and local CHP production data for a given year are ranked according to the amount of net exports;
2. For negative net exports (i.e. imports), the contribution to net exports of wind power (or local CHP) is attributed a nil value since none is exported;
3. The data corresponding to positive net imports are ranked in two different ways: according to the difference between net exports and wind power (or local CHP)
   - When this difference is positive, i.e., net exports exceed production, all of the wind production (or all local CHP) is deemed to have been exported;
   - When this difference is negative, i.e., production exceed exports, the amount of wind production (or local CHP) exported is equal to the amount of net exports.

Once exports are attributed to wind or local CHP, the contribution of the other source to the remaining net exports can be accounted for, simply by using an adaptation of the procedure described above. Figure 11 shows the results of this procedure for each of the years 2000 to 2004. As indicated, the left-hand column shows scenario 1 where exports are attributed to wind and the right-hand scenario 2 where exports are attributed to local CHP.

The first point is that there is significant variability from year to year, in terms of both the total net exports and also the apparent contribution of wind and local CHP to these. For scenario 1, the percentage of the net exports that can be 'blamed' on wind power production range from 58 to 79%, with an average of around 66% over the five years. Even after this, local CHP power contributed to net exports in amounts equal to between a third to two-thirds of those from wind. Under scenario 2, the percentage of the exports that can be 'blamed' on CHP production range from 77 to 94%, with an average of 85%. Therefore, in both cases, the conclusions merely reflect the initial bias, although the higher figure for local CHP in scenario 2 indicates that CHP production matches net exports better than wind power.

Finally, the procedure presented here can also help us to substantiate the critics' '80% export claim' that initiated this analysis. Figure 12 presents the proportion of wind and local CHP power that could be said to be exported according to scenario 1. Clearly, in scenario 1, it could be possible to identify between 44 and 84% of the wind energy production as an 'excess' that has to be exported; but even then between 8 and 40% of the local CHP production is exported too. Figure 13 presents the same approach for scenario 2 and it can be seen that, while 29 to 77% of the local CHP production is exported, a smaller amount (4 to 32%) of wind production is exported.

5 Discussion

From this analysis it is now clear how the wind critics derive their claim that 80% of Denmark's wind production is exported. This figure can be supported if, and only if, the extreme assumption that wind 'causes' the exports is accepted. The opposite extreme, that local CHP 'causes' exports, appears to have an even stronger claim, given CHP's larger percentage contributions to exports and the stronger correlation of CHP production with net exports. Thus the claim that 80% of Danish wind production is exported and therefore 'unwanted' is not reasonable, since equally it could be argued that up to 77% of local CHP production is 'unwanted', which is evidently not the case.

Nevertheless, it cannot be denied that wind power production must be forcing some net exports, as evidenced by the fact that wind and local CHP together seem to contribute most of the net exports. Examples given in [12] and [13] illustrate that the triggers for extreme situations leading to significant import and export include deviations from the forecasted wind availability. As such, perhaps a more reasonable and less arbitrary basis for defining the amount of wind power exported would be to examine correlations between net exports and the degree of error in forecasting wind and CHP production.

6 Conclusion

UK critics of wind power often use the Danish experience to illustrate why wind power capacity should not be expanded. One assertion is that wind power is 'unwanted' since'80% of the wind produced is exported'. This paper has re-examined available data from Western Denmark to explore this issue and to test the validity of this claim.

It was found that monthly net exports from Western Denmark were more significantly correlated with the power output from local CHP than with wind power. A similar conclusion was reached when considering hourly statistics for individual years: in any season, although net exports were well correlated with wind power, they were better correlated with local CHP production.

In order to test the 80% export claim directly, a simple technique was used to correlate and rank hourly net exports, wind power and local CHP. It was found that, depending on whether net exports at any hour were primarily attributed to (or blamed on) wind or local CHP, the amount of wind power deemed to have 'caused' export varied considerably between 58 and 79% of net exports, representing between 44 and 84% of total wind energy production. While these values are in-line with critics' export figures, it should be remembered that this extreme assumption is as arbitrary as assuming that the stronger contributions from local CHP mean that local CHP is responsible for 77 to 94% of exports (corresponding to between 29 and 77% of the local CHP production).

Overall, this study shows that the 80% export claim is an exaggeration, ignoring the most salient observation that local CHP power contributed more to net exports than wind. However, it remains true that there is some degree of correlation between net exports and wind power.

7 Acknowledgements

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Captions to figures:

Figure 1: Map of the Danish electrical networks, interconnections and major generating facilities, after Eltra [8].

Figure 2: Primary energy sources for electricity generation in Denmark in 2002 [9].

Figure 3: Monthly domestic demand, wind power production, and net exports.

Figure 4: Monthly power imports as a function of demand.

Figure 5: Monthly net exports as a function of wind production in Western Denmark.

Figure 6: Monthly net export against monthly local CHP production in Western Denmark.

Figure 7: Monthly local CHP production against monthly wind power production.

Figure 8: Hourly net power exports as a function of wind power production in Western Denmark, January to March and July to September 2000.

Figure 9: Hourly net power exports as a function of local CHP production in Western Denmark, January to March and July to September 2000.

Figure 10: Hourly net power exports as a function of local CHP production in Western Denmark, January to March and July to September 2000.

Figure 11: Respective contributions of wind and local CHP to net exports assuming extreme scenarios assuming exports 'caused' by wind (1) or CHP (2).

Figure 12: Percentage of wind power and local CHP power apparently exported under scenario 1.

Figure 13: Percentage of wind power and local CHP power apparently exported under scenario 2.

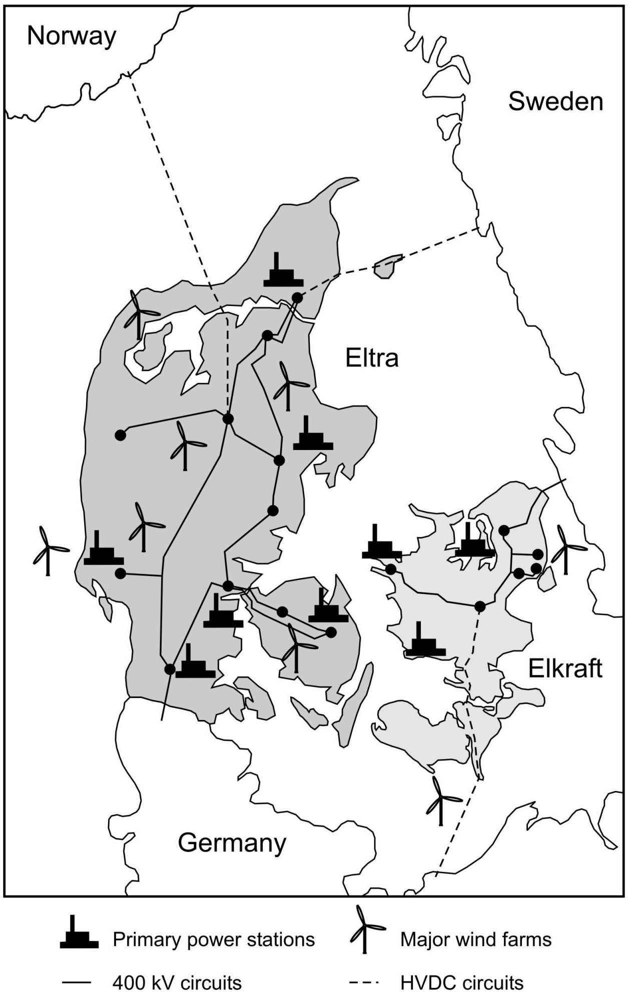

Norway
Sweden
Eltra
Elkraft
Germany
Primary power stations
Major wind farms
400 kV circuits
HVDC circuits

Figure 1

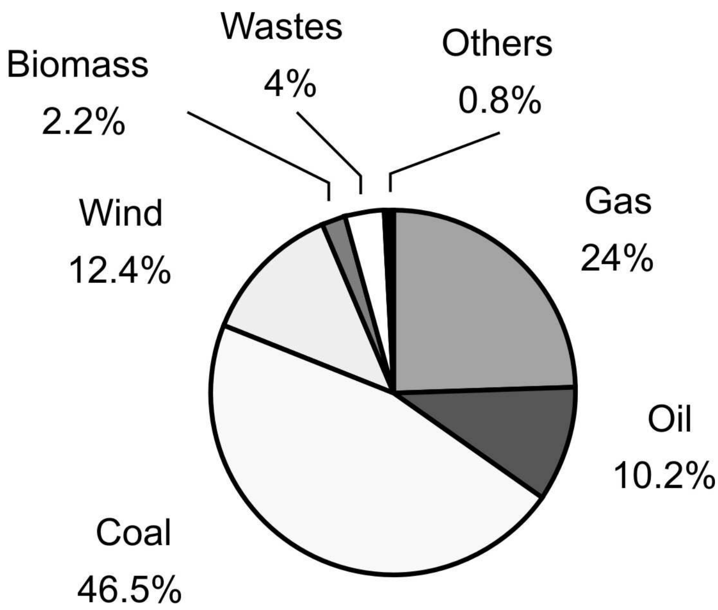


Figure 2

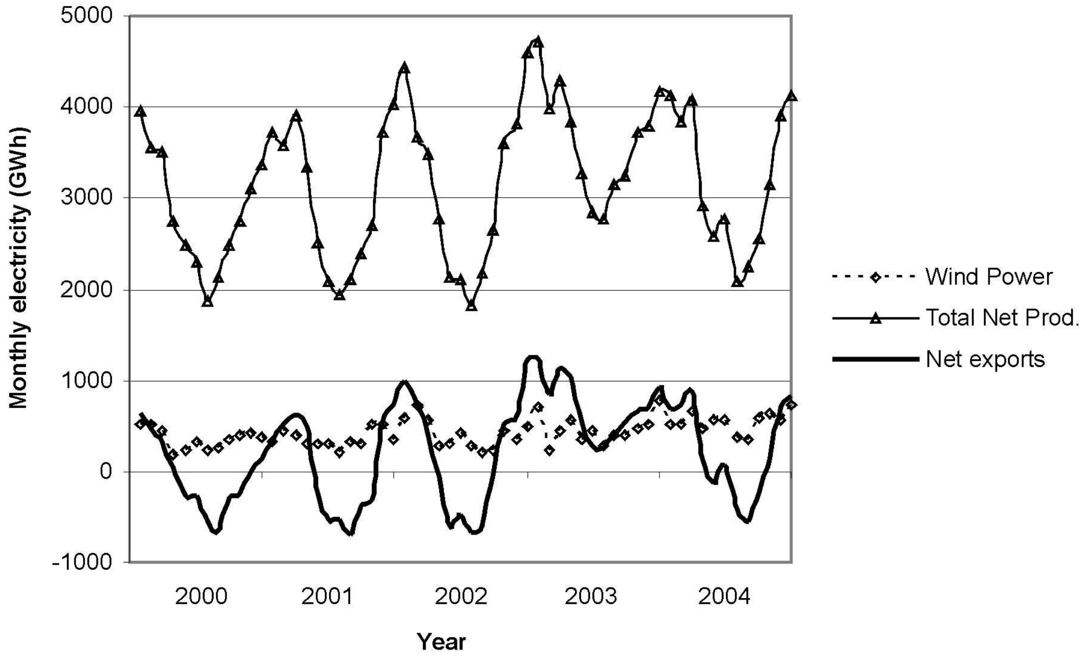
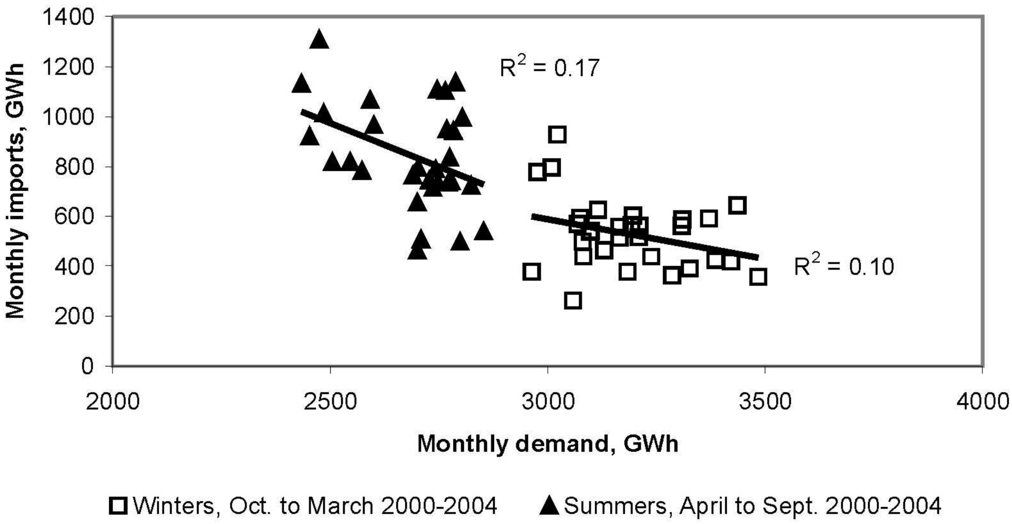

5000
4000
3000
2000
1000
0
-1000
Monthly electricity (GWh)
2000
2001
2002
2003
2004
Year
Wind Power
Total Net Prod.
Net exports

Figure 3



1400
1200
1000
800
600
400
200
0
2000
2500
3000
3500
4000
Monthly imports, GWh
Monthly demand, GWh
R^2 = 0.17
R^2 = 0.10
Winters, Oct. to March 2000-2004
Summers, April to Sept. 2000-2004

Figure 4

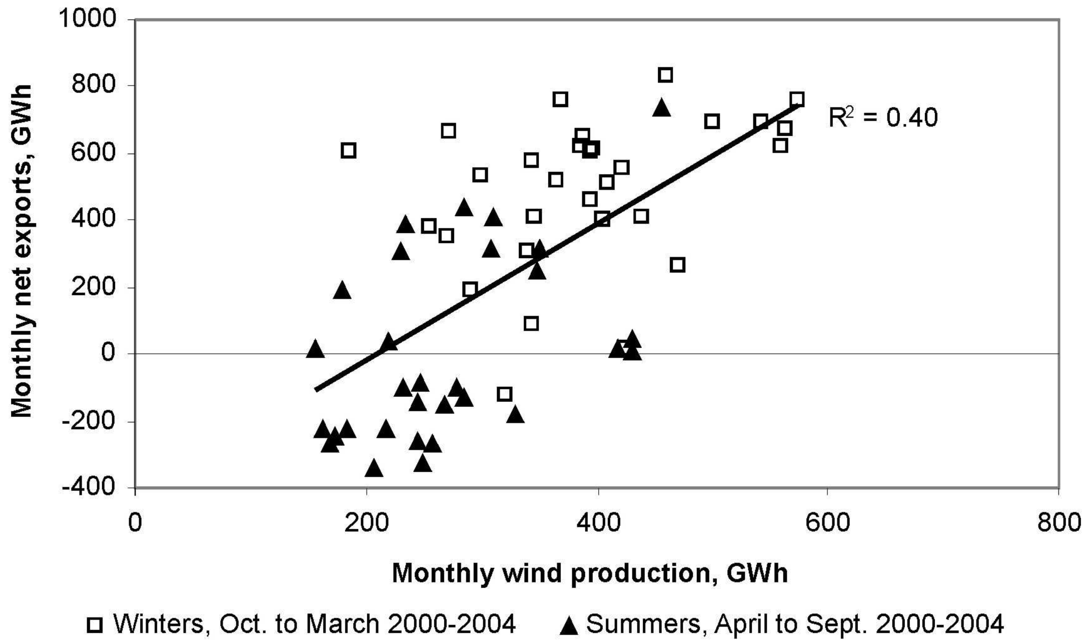

1000
800
600
400
200
0
-200
-400
0
200
400
600
800
Monthly net exports, GWh
Monthly wind production, GWh
R2 = 0.40
Winters, Oct. to March 2000-2004
Summers, April to Sept. 2000-2004

Figure 5

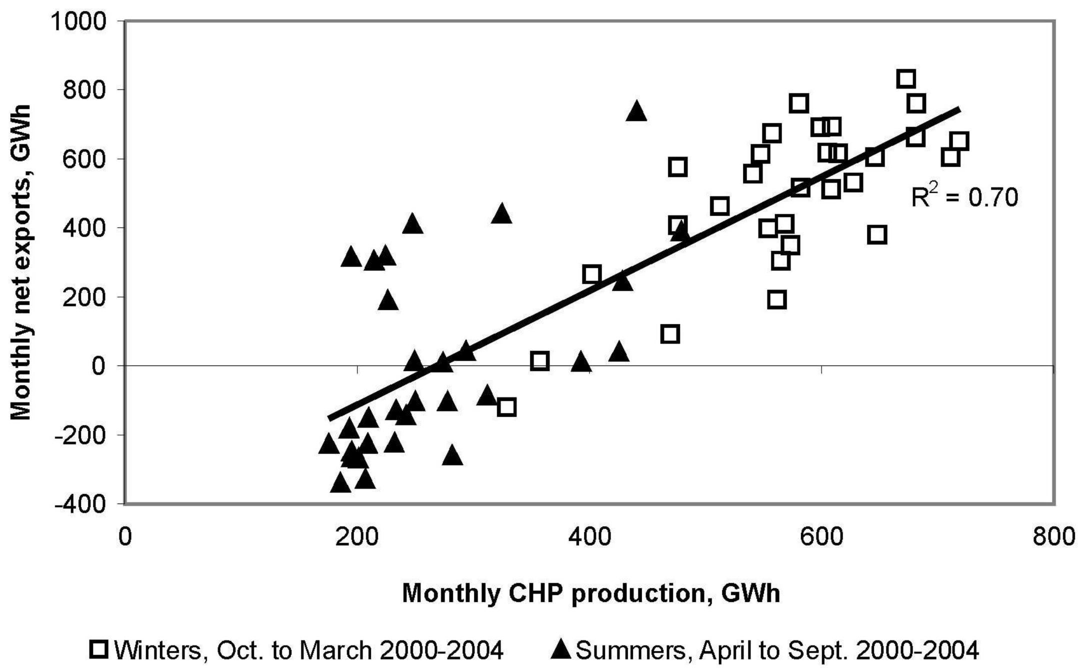

1000
800
600
400
200
0
-200
-400
0
200
400
600
800
Monthly net exports, GWh
Monthly CHP production, GWh
R2 = 0.70
Winters, Oct. to March 2000-2004
Summers, April to Sept. 2000-2004

Figure 6

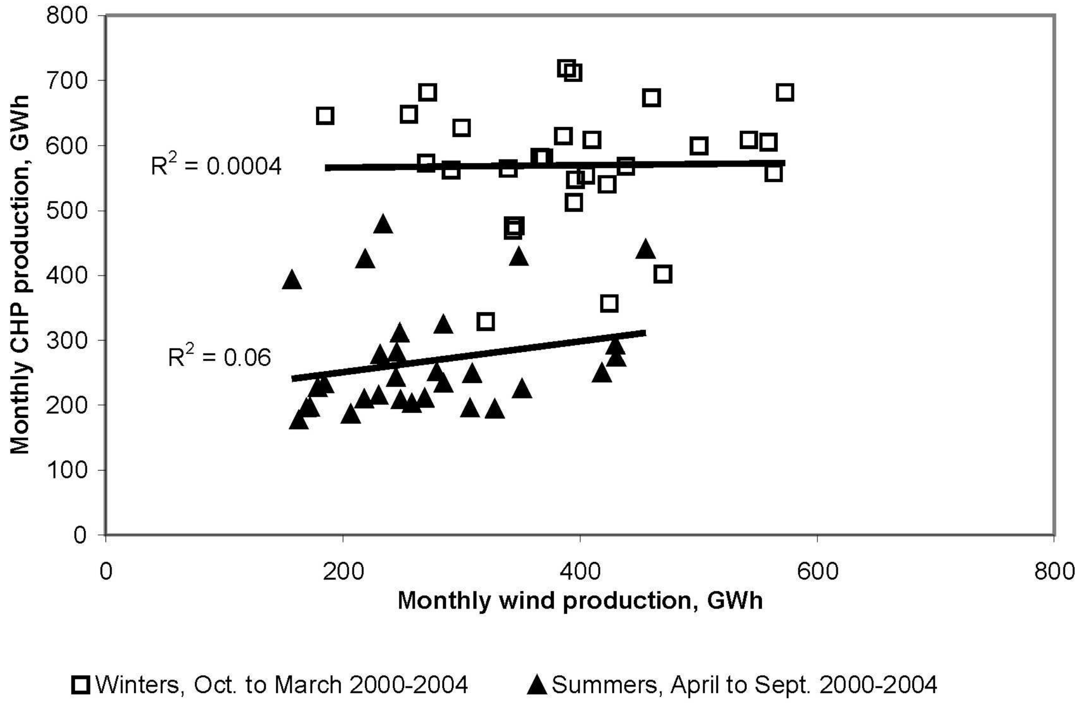
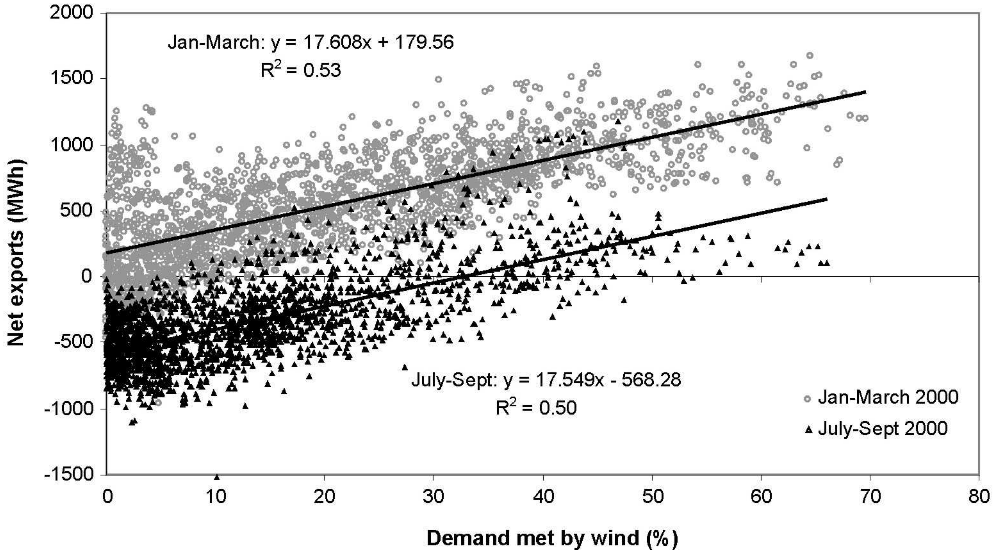

Monthly CHP production, GWh
Monthly wind production, GWh
$R^2 = 0.0004$
$R^2 = 0.06$
0
100
200
300
400
500
600
700
800
0
200
400
600
800
Winters, Oct. to March 2000-2004
Summers, April to Sept. 2000-2004

Figure 7



Jan-March: y = 17.608x + 179.56
R2 = 0.53
July-Sept: y = 17.549x - 568.28
R2 = 0.50
Jan-March 2000
July-Sept 2000
Net exports (MWh)
Demand met by wind (%)
2000
1500
1000
500
0
-500
-1000
-1500
0
10
20
30
40
50
60
70
80

Figure 8

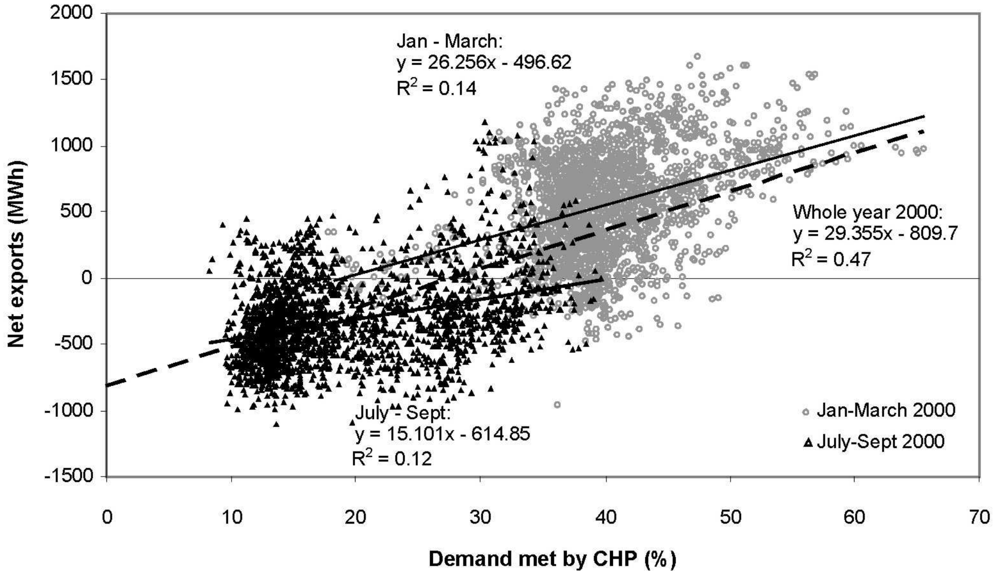

Jan - March:
y = 26.256x - 496.62
R^2 = 0.14
Whole year 2000:
y = 29.355x - 809.7
R^2 = 0.47
July - Sept:
y = 15.101x - 614.85
R^2 = 0.12
Jan-March 2000
July-Sept 2000
Net exports (MWh)
Demand met by CHP (%)
2000
1500
1000
500
0
-500
-1000
-1500
0
10
20
30
40
50
60
70

Figure 9

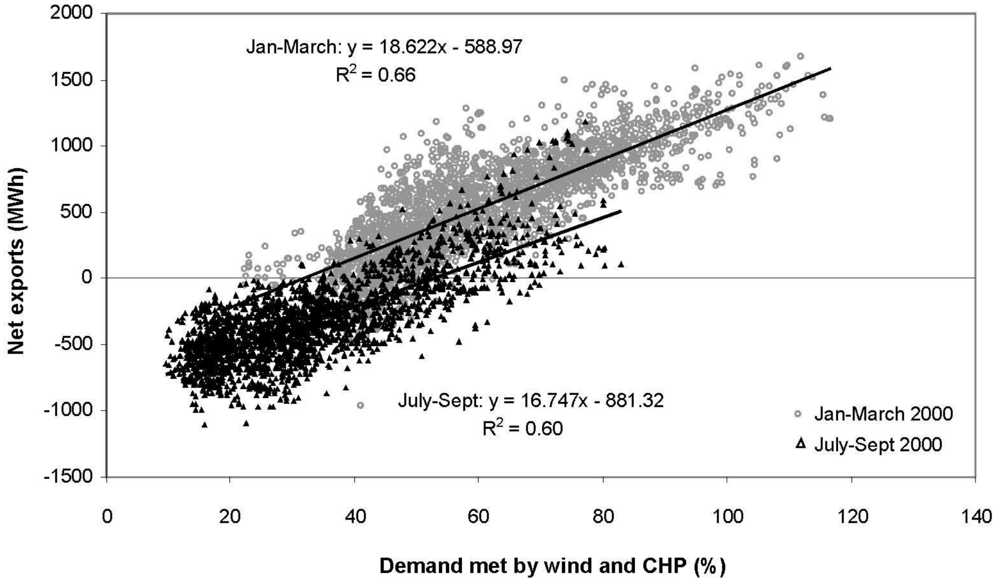
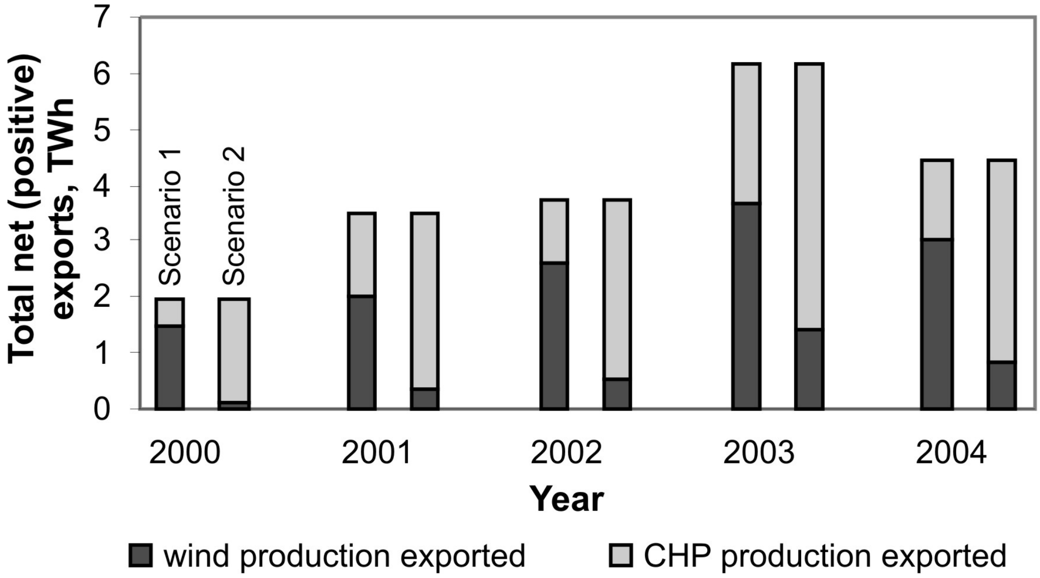
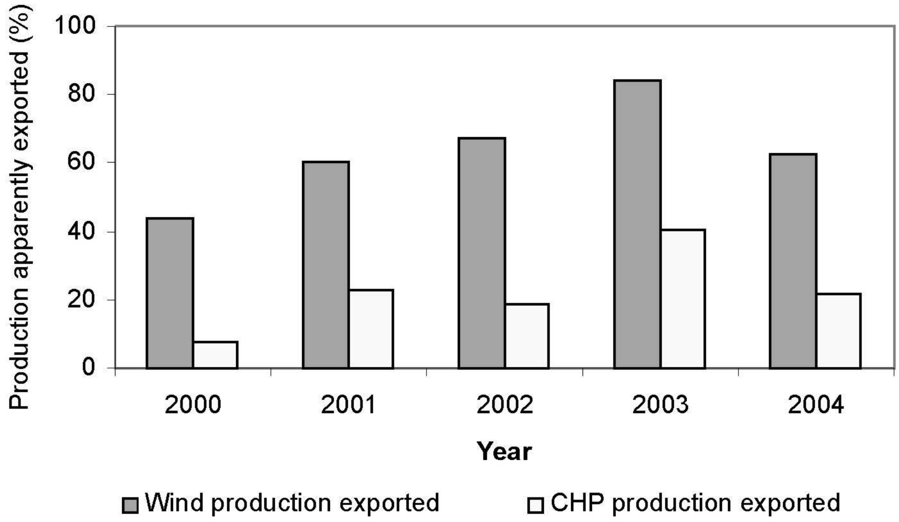

Jan-March: y = 18.622x - 588.97
R2 = 0.66
July-Sept: y = 16.747x - 881.32
R2 = 0.60
Jan-March 2000
July-Sept 2000
Net exports (MWh)
Demand met by wind and CHP (%)
2000
1500
1000
500
0
-500
-1000
-1500
0
20
40
60
80
100
120
140

Figure 10



7
6
5
4
3
2
1
0
Total net (positive) exports, TWh
Scenario 1
Scenario 2
2000
2001
2002
2003
2004
Year
wind production exported
CHP production exported

Figure 11



Production apparently exported (%)
100
80
60
40
20
0
2000
2001
2002
2003
2004
Year
Wind production exported
CHP production exported

Figure 12

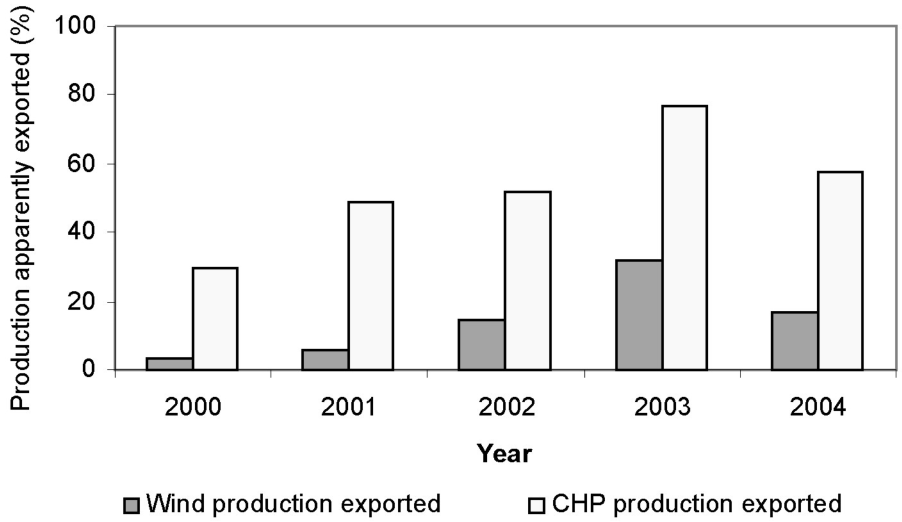

Production apparently exported (%)
100
80
60
40
20
0
2000
2001
2002
2003
2004
Year
Wind production exported
CHP production exported

Figure 13